NBS

Technical Note 244

A HELICOPTER BATTERY SERVICE SIMULATOR

W. G. EICKE, JR.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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A Helicopter Battery Service Simulator

Woodward G. Eicke, Jr.

A semi-automatic helicopter battery service simulator is described in detail. The simulator consists of a programing unit and operational unit for charging and discharging the battery, and peripheral equipment for furnishing charging current and recording data. The design of the program unit is based on the use of stepping switches and is capable of selecting any minute of a week uniquely. The programer is designed to handle a large number of programs but only 8 control units were installed. The capacity of the complete simulator is 3 batteries. The design is such that the simulator can be made fully automatic by the addition of certain data recording equipment.

1. Introduction

The Bureau of Aeronautics, Department of the Navy, requested the National Bureau of Standards to evaluate a new test procedure for silver-zinc or silver-cadmium batteries used in certain military helicopters. This new test procedure represented a radical departure from usual testing methods used for evaluating naval aircraft batteries [1].[1] Under the older specification for silver-zinc batteries, MIL-B-18013A(ASG), 30 April 1956, the cycle life of a battery is determined by discharging the battery at the 1-hour rate for one hour, and then charging it at constant current using the two-rate method with constant-potential charges interspersed at intervals of about 30 cycles [1]. Cycling is continued for a specified number of cycles or until the battery fails to deliver the required ampere-hour capacity. Under the proposed test, batteries would be subjected to short high-rate discharges with recharging being carried out at a constant potential. Cycling would be continued for a specified number of cycles (flights) or until the battery failed to maintain a specified voltage during the discharge. The discharges were designed to simulate the currents required to start a helicopter engine and the charging was designed to simulate that which the battery would receive in service. Table 1 gives a brief description of the test. It should be noted that a discharge is called a start and a cycle of discharge and charge is called a flight.

Table 1. Test Regime for a 14-Cell 12-Ampere-Hour Silver-Zinc Battery

<u>Start</u>	A one-second discharge through an 0.04-ohm resistor followed immediately by a 9-second discharge through an 0.17-ohm resistor.
<u>Flight</u>	Three starts separated by stand periods not to exceed ten seconds, and a 30-minute charge from a constant-potential bus maintained at 27.5 ± 0.1 volts with battery in series with an 0.1-ohm, resistor.
<u>Flight-day</u>	Twenty flights within a twenty-four hour period. The flight-day is divided into two groups of 10 successive flights with a one-hour stand period between each group. At the end of the 20th flight the battery stands in a charged condition for the balance of the twenty-four hours.

Because of the shortness and frequency of the discharges, a new test unit had to be designed and constructed. Analysis of the test program shows that a test unit should meet the following general requirements.

1. The unit should be as fully automatic as possible, and require a minimum amount of attention.

2. The unit must be reliable so that it could be operated unattended during non-working hours.

3. The unit should be simple to operate when not on automatic operation.

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[1] Figures in brackets refer to literature references given at the end of this report.

4. Instrumentation should be provided so that as much test data as possible could be collected automatically.

The best design would be the one which would allow the greatest flexibility of operation without any sacrifice in simplicity or reliability. Accordingly, the Helicopter Battery Service Simulator, which met the above requirements, was designed and constructed at the National Bureau of Standards. This report gives the basic design and principles of operation of the unit.

2. General Description

The Helicopter Battery Service Simulator is a self-contained unit capable of semi-automatically testing three 24-volt batteries in accordance with the test regime set forth in Section 1. The simulator, as it will henceforth be called, consists of four general groups of components: (1) the program machine, (2) the discharge and charge circuits, (3) the instrumentation, and (4) the source of constant-potential charging current. With the exception of some of the instrumentation and the source of charging current (a motor-generator set) all of the components were mounted in a standard 19-inch relay rack. The design of the unit is such that it may operate unattended, except for some minor manual operations required once each 24 hours. Furthermore, instrumentation was provided to automatically record discharge voltage, charging current, and battery temperature throughout the test. The front or control panel contains only those controls, instruments, and accessories which are necessary for the normal operation of the simulator. For the most part, the simulator can be constructed from commercially available components.

Figure 1 shows a photograph of the front of the Helicopter Battery Service Simulator with the lower front panel removed. It can be seen that the unit, as shown, can be roughly divided into five parts. The first four parts comprise the operating controls and the fifth (E) the program machine. Panel A contains the meters, control switches, pilot lights and charging-voltage control necessary for the operation of the simulator as a whole. Panel B contains the indicators which show the setting of the program machine in terms of the day of the week and the hour and the minute of the day (in the photograph the setting of the program machine is 1314). Panel C contains the switches, pilot lights, start counters and ampere-hour meters for the individual test circuits. Panel D contains the terminals required for manual monitoring of the test. The resistors, contactors, and other equipment required for the discharge and charge circuits are not visible because they are mounted in the rear section of the relay rack. All connections to components not mounted in the main cabinet are made through the right hand side of the relay rack.

3. Program Machine

3.1. General

The program machine is the heart of the Helicopter Battery Service Simulator. It is nothing more than an elaborate clock-timer capable of turning on and off a number of electrical circuits at preset times. This particular machine makes use of stepping switches to count minutes, hours, and days and to select the circuit to be controlled. It is the second machine of this type to be constructed at the National Bureau of Standards, the first being built in 1949 [2]. The decision to use the stepping-switch design for the simulator was primarily based on the excellent operating record of the 1949 model. During the ten years of operation, no components failed nor has the unit as a whole had any malfunction. Using the experience gained from the first model it was possible to design a second model with far fewer components and at the same time expand the program-handling capacity of the machine. Although the present model has only eight program circuits, it can readily be expanded to handle a hundred or more by merely adding more control relays. The only limitation on the operation of the machine is the maximum of nine programs that can be turned on or off in any one minute. Excluding the source of the timing and control pulses the basic program machine is constructed entirely of telephone-type relays and stepping switches. The expected life of each component is probably in excess of ten million operations, or about twenty years.

Except for the time indicators mounted on panel B (See fig. 1) the whole program machine is located in the lower portion of the relay rack and is accessible from both the front and back of the relay rack. For convenience in discussing the design and operation, the machine will be divided into three parts:

1. the timing circuit
2. the time-indicating circuit
3. the program-control circuit

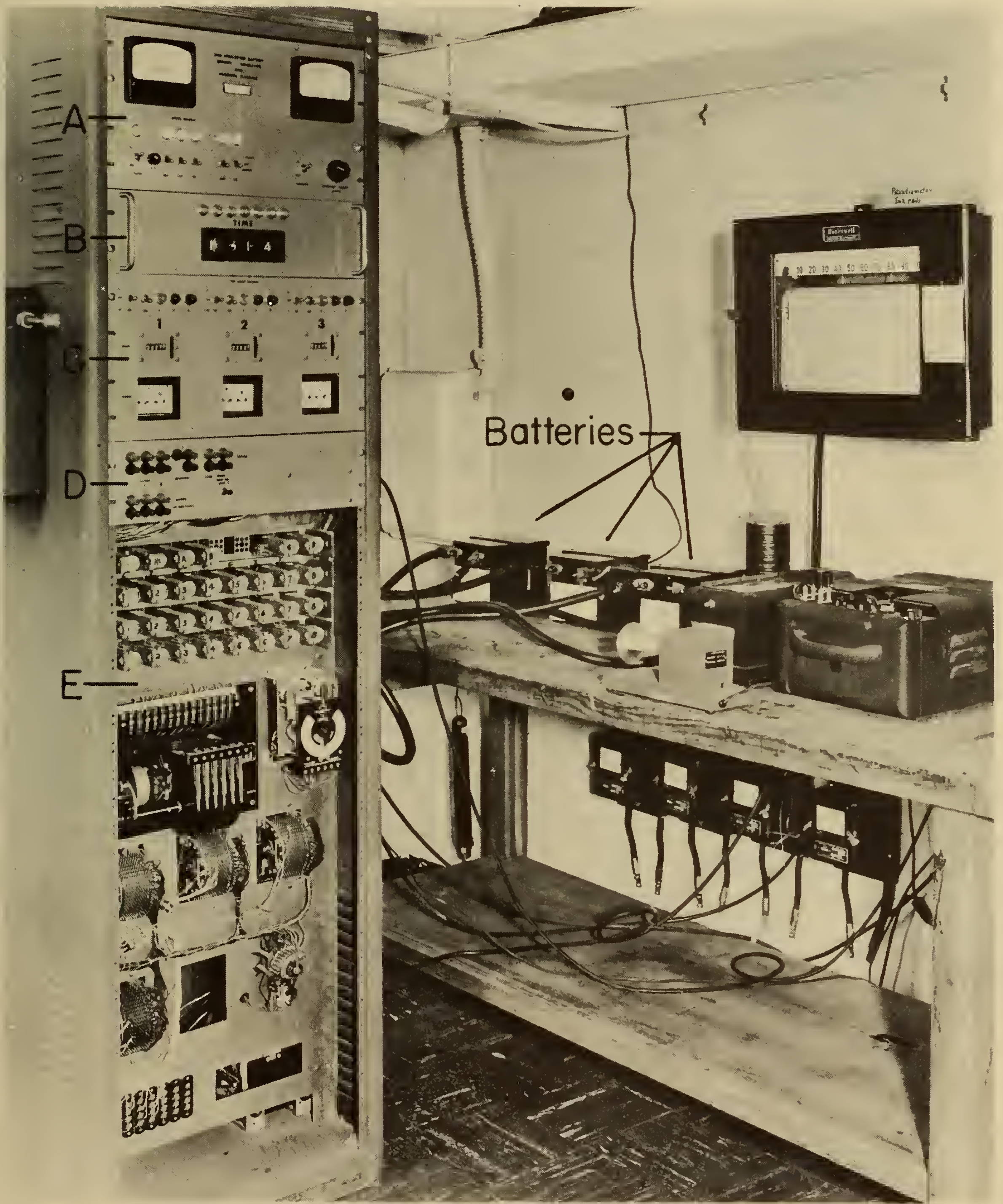

Figure 1 A photograph of the complete Helicopter Battery Service Simulator.

3.2. Timing Circuit

The function of the timing circuit, as its name implies, is to time. The fundamental unit of time in this particular machine is the minute, but it is possible to use any other unit and still use the same basic design. Timing is accomplished by counting pulses in terms of days, hours, and minutes. In this manner each minute of the week (there are 10,080 minutes in a week) is uniquely determined by the position of three counters, one for the minutes, one for the hours, and one for the days. In figure 2a and 2b are shown a block diagram and a schematic diagram of the circuit used to accomplish the timing in the above manner. The general operation of the timing circuit is clearly shown by the block diagram in figure 2a. Referring to figure 2a, the cam timer generates one pulse each minute and this pulse advances the minute-counter, which counts from 0 to 59 minutes. Upon receipt of 60 such pulses the minute-counter starts counting over again and at the same time it advances the hour-counter one unit (hour). The hour-counter counts from 0 to 23 and once each twenty-four hours the hour-counter generates a pulse which advances the day-counter one unit (day) and at the same time the hour-counter starts to count over again. The day-counter counts from 1 to 7 before starting over again. Thus, counters having a total of 91 positions uniquely define each of the 10,080 minutes of the week.

The detailed circuit required to accomplish the timing is shown in figure 2b, and specifications for the components are given in Table 2. Since only 26-point stepping switches are used, three are required to count the sixty minutes, and in the figure they are designated M1, M2 and M3. In order to maintain symmetry in design only twenty positions on each switch are used for counting. The hours are counted by means of a single 26-point switch and the days by an 11-point switch. These switches are designated H and D, respectively. Referring to figure 2b it can be seen that the timing pulses from cam 1 of the timer (TC) operates the relay (RT) which in turn transmits the pulse to the correct minute stepping switch through the closed contact of the off-normal springs (ONS) on the switch to be stepped (see solid lines of fig. 2b). As shown in the figure only the M1 switch can operate because the ONS contacts on M2 and M3 are open, thereby preventing the step magnets from receiving pulses from RT. Thus M1 will advance one position with each operation of RT. When the wipers on M1 are at position 19 the next pulse, in addition to advancing M1 one position, will cause M1 to generate a pulse which will advance M2 from the position marked OFF to position 20. The circuit used to generate this pulse is shown by the dashed lines from contact 19, bank 2[2] to the step magnet of M2 via the interrupter spring of M1. It can be seen that the only time that this circuit is operative is during the minute that the wipers are position at contact 19 (19th minute of the hour). When M1 advances one step from contact 19, the "homing circuit" shown by the dotted lines from contacts 20, 21, 22, 23, 24 to the step magnet of M1 via the interrupter springs on M1, automatically steps M1 to the OFF position. When M1 reaches the OFF position the contacts of the off-normal spring are opened, thereby preventing the step magnet of M1 from receiving any more pulses from RT. Since the switch steps itself at the rate of 40-60 setups per second during homing operation the time required for M1 to go from contact 19 to OFF is in the order of 0.1 second. The operation of M2 is identical to that of M1; M3, however, in addition to operating in the same manner as M1, also advances the hour stepping switch (H) one step at the same time that it advances M1 from OFF to position 0, and itself from 59 to OFF. The hour switch operates in much the same manner as the minute switches except that the pulse which advances the hour switch is also fed into the wipers of bank 2, and instead of stepping to the OFF position after leaving position 23 (23rd hour) the switch steps through OFF and starts over to 00 by means of a "homing circuit". This pulse is used to advance the day switch one step (day) when the minute switch advances from 59 to 00 and the hour switch from 23 to 00. The day switch counts from Sunday to Saturday and on the pulse which advances the other switches from 2359 Saturday to 0000 Sunday the day switch is reset to Sunday by means of the "homing circuit" shown by the dotted lines. The basic circuits used are quite simple and straightforward; however, one word of caution is necessary. The bank (level) 1 on each switch must be bridging (shorting) to prevent arcing during homing and all other levels must be nonbridging to prevent the occurrence of "sneak paths" which would cause false operation of the switches or programs.

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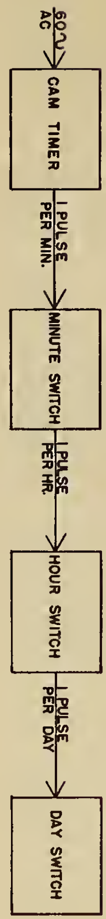
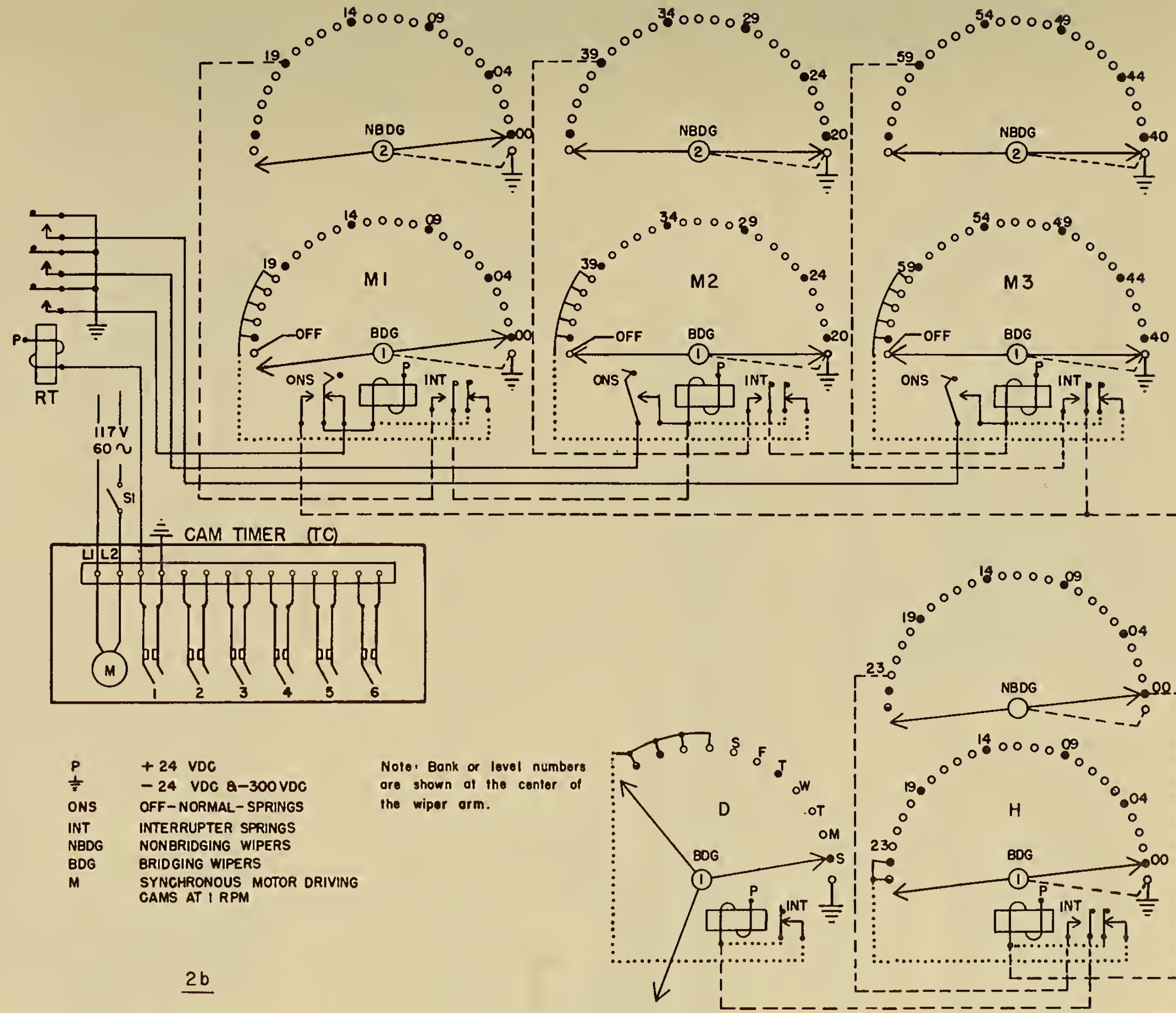
[2] The bank or level number is shown in the center of the circle that indicates the pivot point of the wiper arms.



2a



2b

Figure 2 Operating portion of the timing circuit.

Table 2. Specification of Major Program Machine Components

Item	Description	No. required
M	Minute stepping switch; 24 vdc; equipped with arc suppressor; 26-point; 1 bridging level; 11 nonbridging levels; 1 Form A and 1 Form B interrupter springs; 1 Form C off normal springs.	3
H	Hour stepping switch, same as M except no off normal springs are required.	1
D	Day stepping switch; 24 vdc; equipped with arc suppressor; 11-point; 1 bridging level; 5 nonbridging levels; 1 Form C interrupter spring combination.	1
RT	Relay, telephone type; 24 vdc; Contacts: 5 Form A, 1 Form B, and 1 Form C.	1
RD	Relay, telephone type; Slow operate (0.08-0.10 sec operate delay); Contacts: 4 Form C.	1
TC	Cam timer; 117 vac; 60 cps; 1; 6 adjustable cams; cam rotation: 1 rpm; one pair of contacts per cam.	1
	"Nixie"* indicator, type 6844A, manufactured by Burroughs Corporation (see manufacture literature for detailed specifications).	4
RC1	Relay, telephone type, 24 vdc; Contacts: 6 Form A, 1 Form C, and 1 Form D.	6**
RC2	Relay, telephone type, 24 vdc; Contacts: 1 Form B.	6**
RC3	Relay, telephone type, 24 vdc; Slow release (release delay 0.1-0.2 sec.) Contacts: 2 Form A.	6**
TE	Timer, electronic; 117 vac, 60 cps, 1; timing intervals: 0.05-30 sec and 0.05-3.0 sec; operature on closure of external contacts; resets on opening of external contacts; load contacts closed during operation of the timer.	1

**One required for each program.

3.3. Time-indicator Circuit

The detailed circuit used to indicate the time of day and the day of the week is shown in figure 3 and the specifications of the components are given in table 2. All indicators are of the neon type and operate from a 300-volt d.c. supply. For safety, the negative side of the supply has been made common to the -24 volt d.c. supply and all of the high-voltage parts are completely enclosed to prevent accidental contact while working in the vicinity of the indicators. The indicators for the days are NE-51 neon lamps mounted in an enclosed pilot light assemble. Letters have been placed in front of the lens to show the day of the week. As can be seen from figure 3, bank 1 of the day switch is used to operate the indicators. The minutes and hours are indicated by means of "NIXIE"* indicator tubes (IND). These indicators are gas filled, cold cathode tubes having a common anode and 10 numerals, each of which acts as a cathode upon the application of a potential. As shown in figure 3, banks one and three are used for both the hours and minutes. Bank 1 is used for the tens and bank 3 for the units. The resistor in the anode circuit acts as a current limiter and the actual value is determined by the supply voltage available. For the correct resistor the manufacturer's literature should be consulted.

3.4. Program-control Circuits

The program-control circuits can be divided into two sections, (1) the program-selector portion and (2) the control-relay portion. The components which comprise the program-selector portion are used for the selection of all programs whereas one set of control relays are required for each program. In figure 4a is shown, by means of a block diagram, the operation of typical program circuit. The control pulse is generated by the cam timer (TC), and is transmitted either directly to the day selector, or to the day selector via the delay relay (RD). When the pulse goes through the delay relay the output from the relay is a pulse of the same duration as the original but the start of the pulse

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*NIXIE is the trade mark of the Burroughs Corporation.

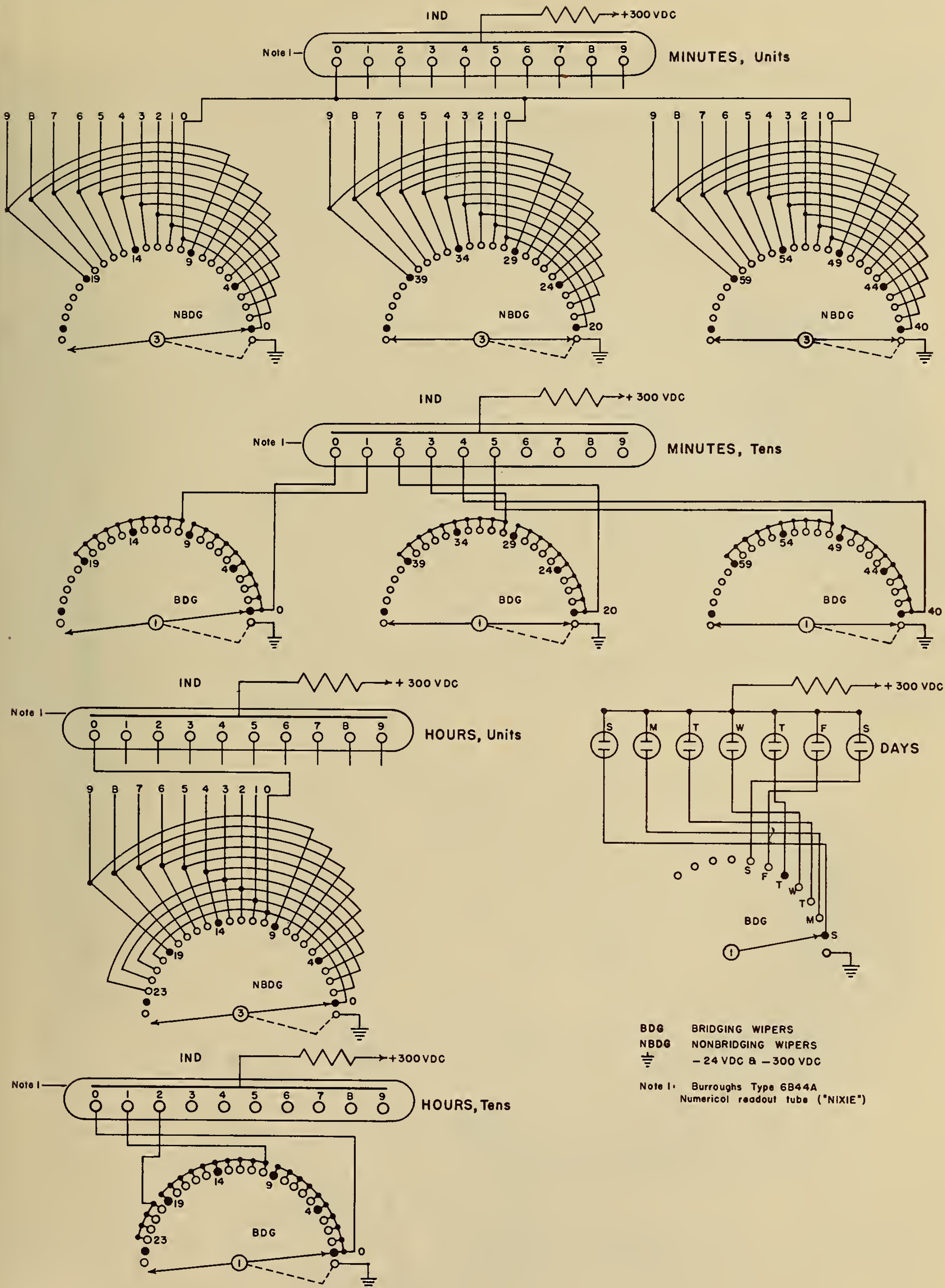
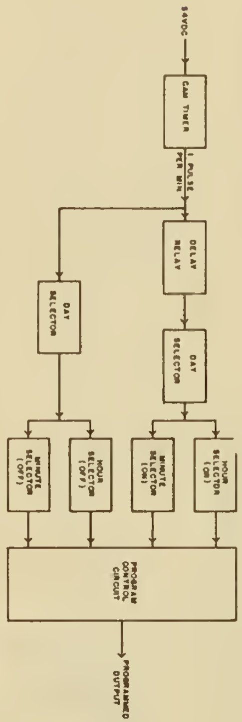
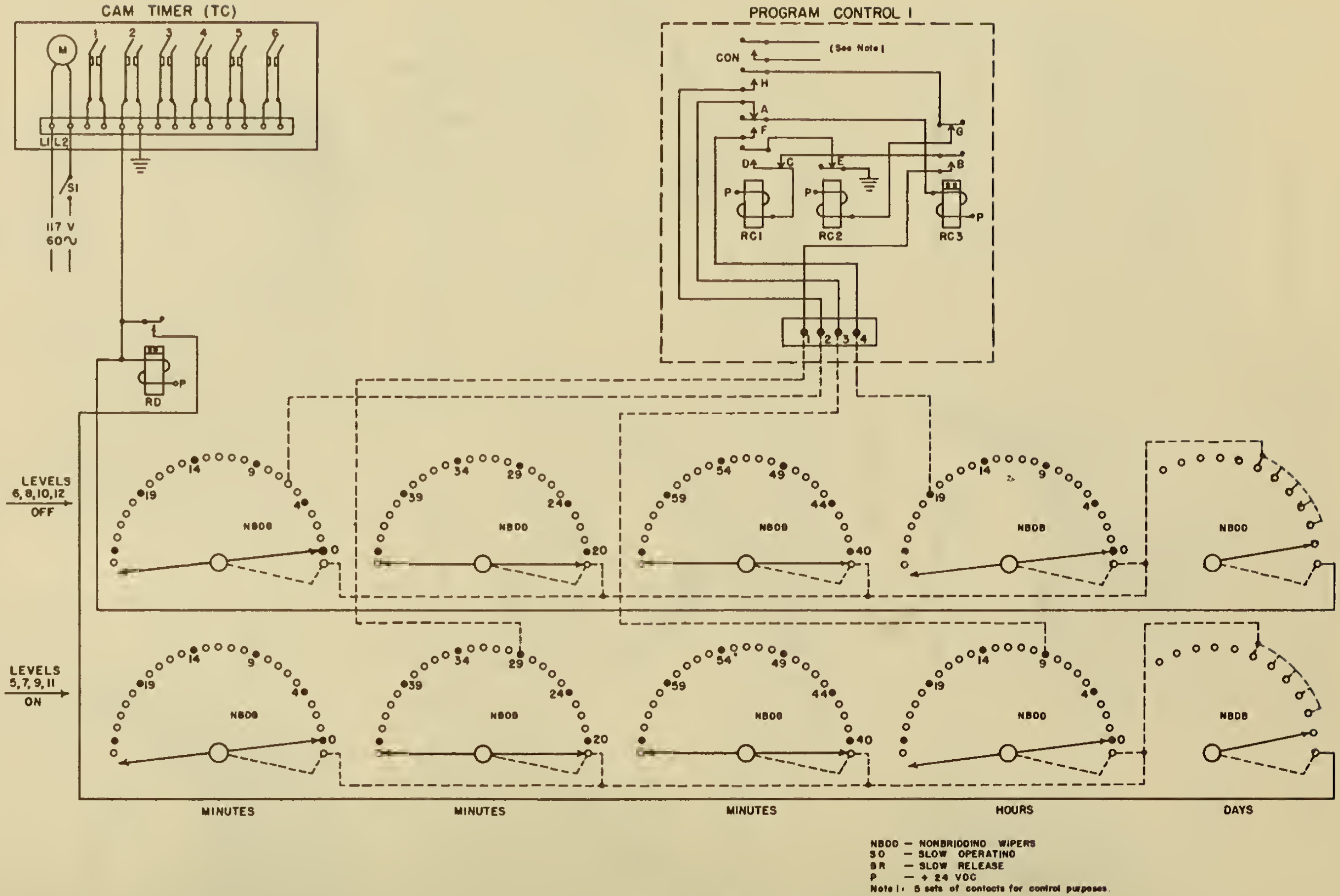


Figure 3 Indicator portion of the timing circuit.



4A



4B

Figure 4 Program control portion of the timing circuit.

lags the start of the original pulse by approximately 0.1 second. This delay is necessary in order to insure the proper sequence of operation between several programs. A further discussion of the operation using the delay pulse will be given later in this section. The pulse enters the day selector where it is programmed for the desired days of the week. The programmed pulses leave the day selector and are fed to both the minute and hour selectors where the desired minutes and hours are selected. There are now two outputs, one programmed for days and minutes, the other for days and hours. These outputs are then fed into the control relays which operate the citcuit to be controlled. The control relays are arranged in such a manner that they will operate only upon the receipt of simultaneous pulses from the hour and minute selector. Since the delay between the regular and the delayed pulse is small compared to the pulse length (which is greater than one second) the two types can be considered as simultaneous pulses. Thus, in order to turn a program on and off four pulses are required, one ON for the minutes, one ON for the hours, one OFF for the minutes and one OFF for the hours.

In figure 4b is shown the detailed circuit for one set of control relays while table 2 gives the specifications for the individual components. The stepping switches shown are the same ones as previously discussed; however, only those banks directly related to the program controls are shown. The banks used for program selection and control are 4 through 12, inclusive, for the minutes and hours, and 2 through 6 for the days. Referring to figure 4b it can be seen that the pulse generated by cam 2 of TC is transmitted to the day switch either directly or via the delay relay (RD). It enters the wipers of the day selector switch and leaves via the contact on which the wiper is stopped (provided a connection is made to that contact). The day programmed pulses are then sent to the minute and hour selector switches where they enter the switch at the wipers and leave via the contact on which the wiper is stopped. The connections between the day selector switch and the minute and hour selector switches are shown by dashed lines instead of solid lines. This is to indicate that these connections are movable and are made to set up a given program or programs. This same convention is also used to show the connection between the terminals on the stepping switches and the input terminals of the program-control relays. The control relays are connected to the minute and hour selector switches by temporary leads. The lead wires can be seen in the lower left corner of panel E (fig. 1). The wires are run from the terminals which are connected to the program control relays to the correct contact on the stepping switches. The wires are kept in order by a number of rings through which each wire passes. Although figure 4b shows the circuit for one program control unit, it will be more convenient to analyze the circuit in two parts; the first, the ON operation, and second, the OFF operation. The two circuits are shown in figures 5a and 5b. The first shows the program in the OFF position and the second with the program ON. Only one relay (RC1) is energized while the program is ON. In each drawing only that wiring necessary to the operation to be discussed is shown. Briefly, the operation of the program control circuit is as follows:

<u>OFF to ON</u>. Referring to figure 5a, imagine that pulses from minute and hour selectors have been simultaneously applied to terminals 1 and 3. When this happens the pulse from 3 passes through the closed contacts A and energizes the coil of RC3. Upon the energization of RC3 the contacts B are closed allowing the pulse terminal 1 to pass on to the coil of RC1 through the closed contacts C. When the coil of RC1 is energized the contacts D are closed and then the contacts C open. (Here make-before-break contacts are used). Relay RC1 is locked in the ON position by means of the ground applied through the closed contacts E on RC2. Also, upon the energization of RC1 the five sets of control contacts (CON 1, 2, 3, 4, and 5) are closed and the contact A opens, thereby removing the current from RC3. Since there is a possibility that the contact D might open before C closes, a slow release relay is used for RC3. In this way contact B will not open for approximately 0.1 second after contact A opens.

<u>ON to OFF</u>. Figure 5b shows the control relays with the control relay (RC) in the operated position (Program ON) and no pulses applied to either 2 or 4. Now imagine OFF pulses applied to the terminals 2 and 4. When this happens the pulse from 4 is transmitted through the closed contact F, thereby energizing RC3. Upon the operation of RC3 the contact G is closed. The closure of G completes the circuit between terminal 2 and RC2 via the closed contact H of RC1. It must be noted that the pulse from 2 can only reach RC2 when RC1 is operated because of the contact H. When RC2 operates, the closed contact E is opened, thus opening the holding circuit for RC1. As a result the current is removed from RC1 and the relay is restored to its normal (unoperated) position and the control circuits (CON 1, 2, 3, 4, and 5) are opened.

Up to this point nothing has been said about how the terminal 1, 2, 3, and 4 are connected to the terminals of the stepping switches. In fact, the actual connections will depend upon the specific program desired. Thus, terminals 1 and 2 may be connected to either the minute or hour switches and 3 and 4 to the hour and minute switches. One other property of the circuit is that terminals 3 and 4 may be connected together, but <u>UNDER NO CIRCUMSTANCES MAY 1 AND 2 BE CONNECTED TOGETHER</u>. In figure 6 are shown three general ways in which the program-control relays may be connected to the selector switches. These three methods will serve for all programs normally encountered in battery testing. It will be seen that a particular program may be operated many times a day from the same set of program-control relays, provided that the following precautions be observed:

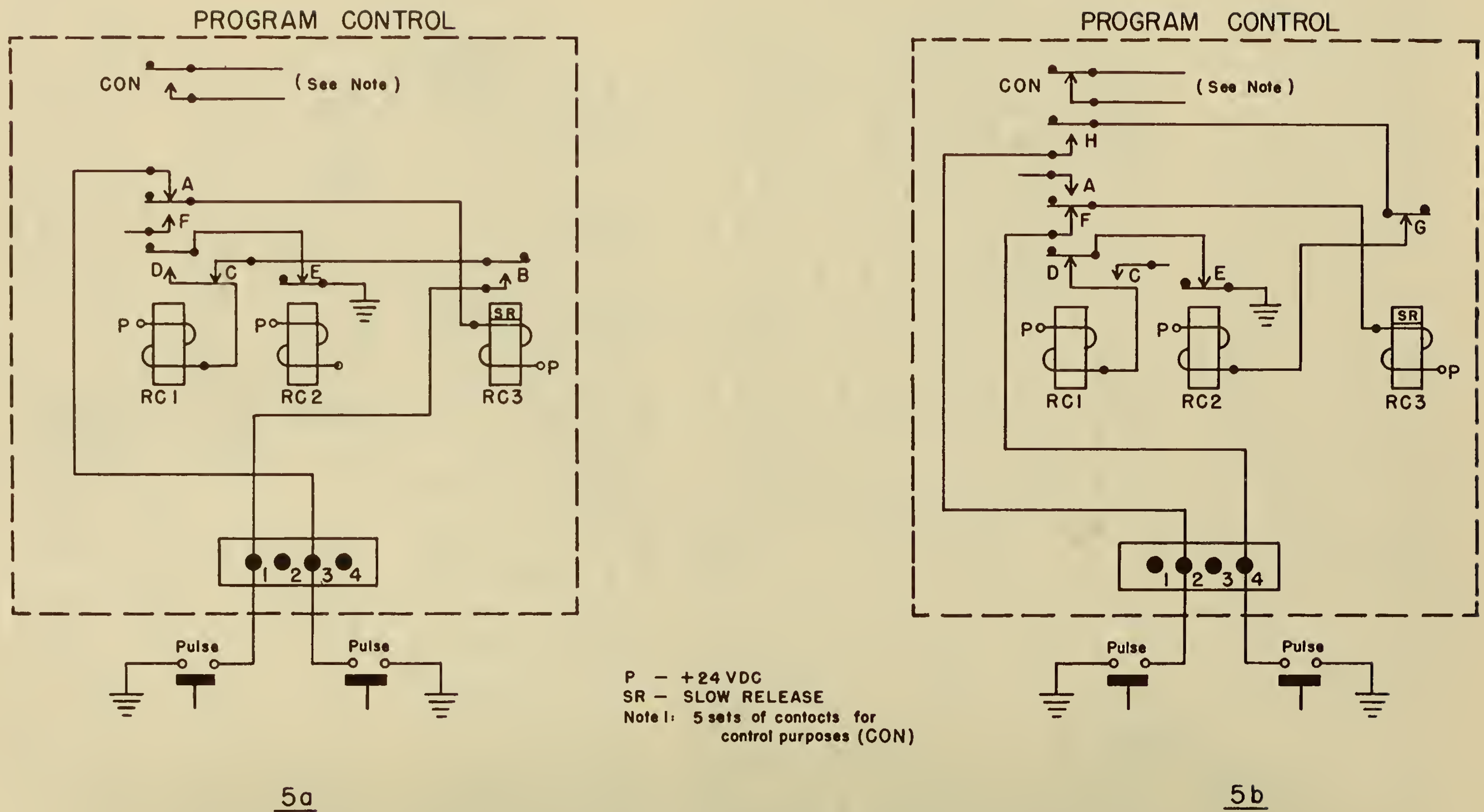


Figure 5 One set of program control relays.

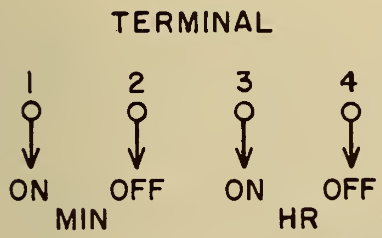
1. For programs which must repeat the ON intervals during a 24-hour period, the minutes at which the program goes on and off must always be the same for each ON period.

2. If a program has several ON periods during an hour and repeats during several hour periods, the ON periods during any given hour must be the same as for all other hours in which ON periods occur (see example under TYPE II fig. 6).

3. The programs for any one day must be the same as for all days for which programs are desired.

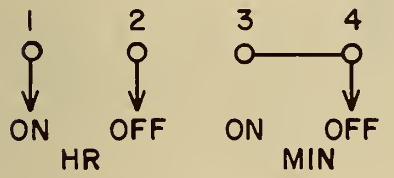
In the event that the above restrictions cannot be observed, it will be necessary to use one set of program-control relays for each part of the program which violates the above restrictions.

TYPE I



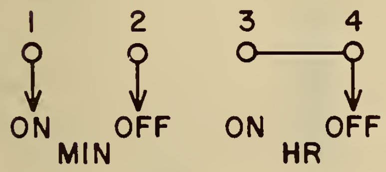
Each terminal connected to a different minute and hour. For use when a program is greater than one hour but not an integral number of hours. (1 and 2 must not be connected to the same minute). May be programmed for more than one operation per day if the ON and OFF minutes are the same for each interval.

TYPE II



Terminals 1 and 2 connected to different hours: 3 and 4 connected to the same minute. For use when a program is an integral number of hours. May be programmed for more than one interval per day so long as only <u>one</u> minute is used for control.

TYPE III



Terminals 1 and 2 connected to different minutes: 3 and 4 connected together to the same hours. For use where the minute interval of the program is less than 60 minutes. The program may repeat during various hours.

<u>Figure 6</u>

Connection for program control relays
(Arrows indicate connection to appropriate
level of minute or hour switch)

Since in testing storage batteries it is often necessary to have one program going off and another one coming on at the same time, some provisions must be made to insure that there is not a momentary overlap in the programs. This overlap is prevented by delaying the ON pulse with respect to the OFF pulse as described in the first paragraph of this section. The delay used in this machine is approximately 0.1 second, therefore, the circuit to be turned on is not actuated until 0.1 second after the circuit to be turned off receives its pulse. This delay is sufficient to insure that all contactors, relays, etc., to be turned off are, in fact, off before the next set of relays, contactors, etc., are operated.

3.5. Special Timing-Circuit

In order to obtain the desired programs for the helicopter battery simulated service test the basic 1 minute increment just described must be further subdivided. To accomplish this further subdivision, additional cams were provided on the cam timer (TC) and an electronic timer adjustable from 0.1 to 3 seconds was used for very short programs required for the 1-second high-rate discharge. In figure 7 is shown a complete sequence diagram of the operation of both the special timing; timing pulse and program pulses used in normal operation of the program machine. A total of 6 cams were provided on the cam timer each operating independently of the others. The solid lines indicate circuit closures. The actual circuit is shown in figure 8. It should be noted that power is only available to cams 3, 4, 5, and 6 (the cams used to control the discharge) only while either RC1-1, RC1-2 or RC1-3 are operated. These are the three control relays which connect the three test batteries, one at a time, to the discharge circuit.

4. Helicopter Battery Service Simulator

4.0. General

In this section the helicopter battery service simulator and its operation will be described. Since the program machine has been described in detail in Section 3, it will be assumed that the proper programs are available at the control contacts of the program-control relays. (See Note 1 fig. 4B). The simulator proper consists of the last three components mentioned in Section 2, namely: (1) the discharge and charge circuits, (2) the instrumentation, and (3) the source of constant-potential-charging current. The complete circuit for the simulator is shown in figure 8. In this figure all pertinent parts of the simulator are shown (note that only the control contacts on the program-control relays are shown). In the subsequent section the three portions of the simulator will be described in detail. However, before discussing the circuits a brief mention of the programming is in order.

The Helicopter Battery Service Simulator requires six programs in order to carry out the test regime set forth in table 1. Three programs are required for the discharge, one for the charge and two for operation of instrumentation, accessories and the generator. The test regime used for the three batteries was essentially that described in table 1 except that the charge has been reduced from 30 minutes to 27 minutes in order to make one flight 30 mintues. Since only one discharge circuit is used, each battery is discharged separately and the discharge period is so programmed that three starts are obtained during one minute. In figure 9 are shown the details of the overall program. Part A shows the programming of the three starts, part B shows one complete flight for three batteries, and part C shows one complete flight day. Although this is not the only possible program, it was found that this particular arrangement worked very well.

4.1. Discharge and Charge Circuits

These circuits are shown in figure 8 by means of the heavy lines. There are 3 charging circuits, a high-rate discharge circuit and a low-rate discharge circuit. Each battery has a separate charging circuit; however, on discharge each battery is connected, in turn, to the discharge circuits, thereby insuring that each is discharged under the same load conditions. During the discharge the low-rate contactor is closed for the whole 10 second period. For the high-rate discharge a second resistor is placed in parallel with the low-rate resistor. The contactor used for paralleling is controlled by the electronic timer (see fig. 8). Since the discharges are carried out at constant resistance, it was necessary to take into account the resistance of all parts of the circuit. Therefore in designing the physical layout of the circuit, precautions were taken to see that all circuit elements not common to all three batteries had very nearly the same resistance. The resistors proper were constructed at the Bureau using a resistance ribbon (3/4-inch wide by 0.040-inch thick) of low thermal coefficient. The ribbons were arranged so that the current through each did not exceed 125 amperes. The resistors were housed in the upper rear portion of the simulator cabinet and a fan was provided to remove the heat generated. The fan was mounted in the top of the cabinet and so arranged that the air flow was from the bottom of the cabinet to the top and was programmed so that it was operating any time the generator control-circuit was activated. Each resistor was provided with a means of adjusting its value and the total circuit resistance for both the high and low rates was adjusted so that the total resistance as measured at the lugs, to which the battery was connected, was the prescribed value. To monitor the current, a 0-400 ampere ammeter was placed in the discharge circuit. Aircraft contactors, rated at 250 amperes, were used to make and break the discharge circuit. Because of the circuit arrangement the contactors in the low-rate circuit, which also served to connect each battery in turn to the resistor, close approximately 10 milliseconds before the high-rate contactor's hence at no time did any contactor make or break currents exceeding the rating of the contactor.

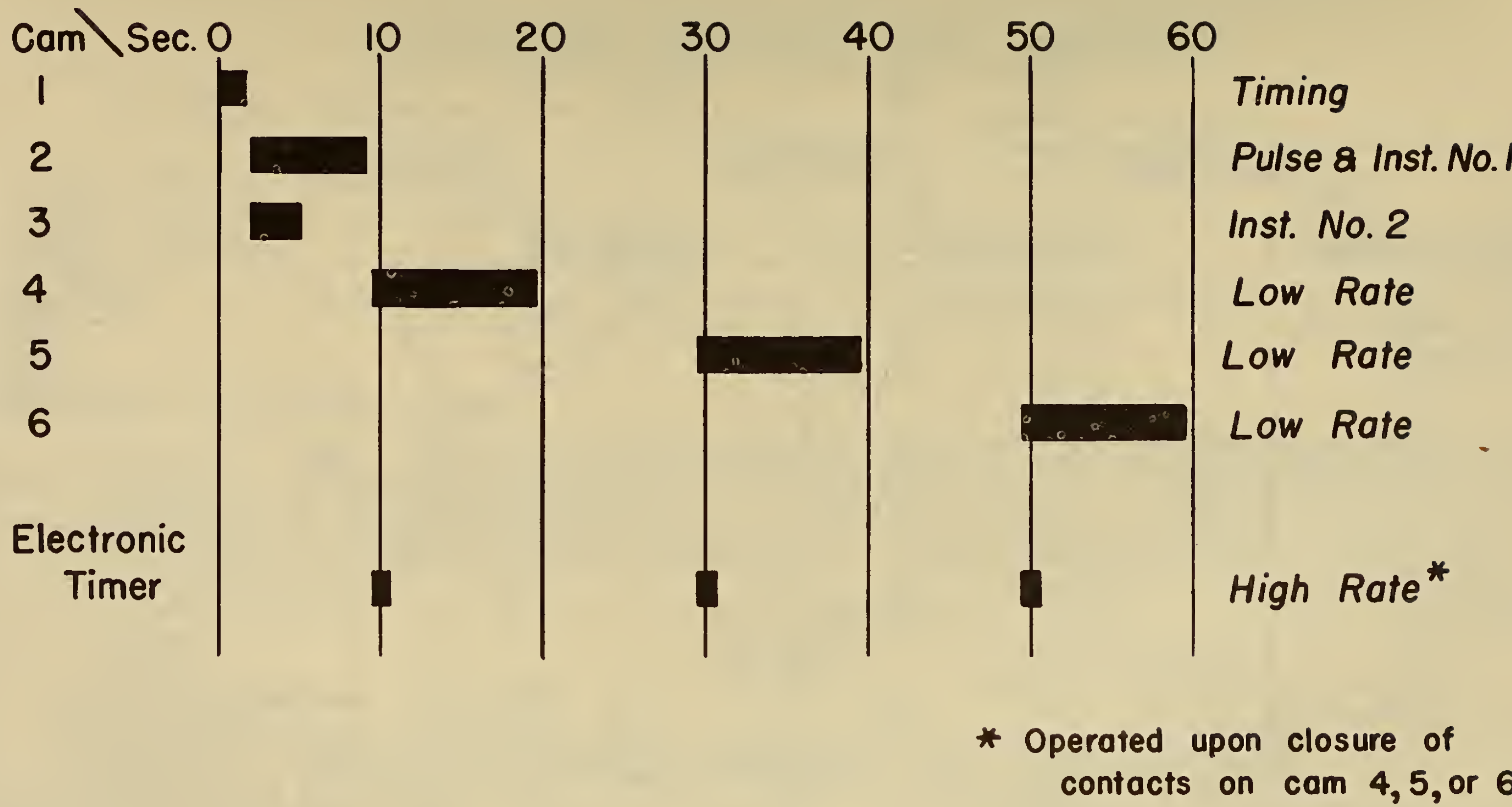


Figure 7 Sequence diagram for cam and electronic timers.

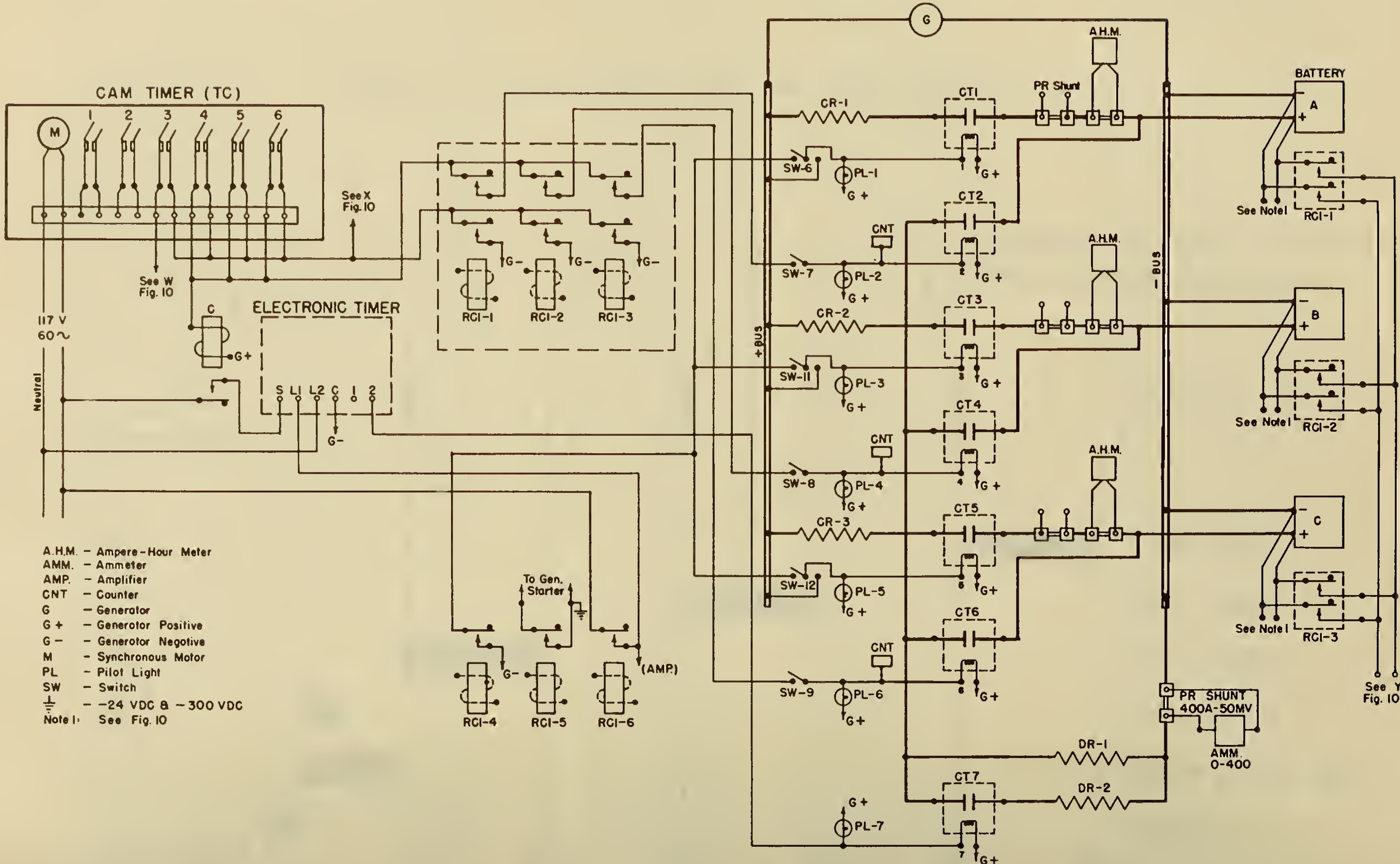


Figure 8 Charge and discharge circuits for the simulator.

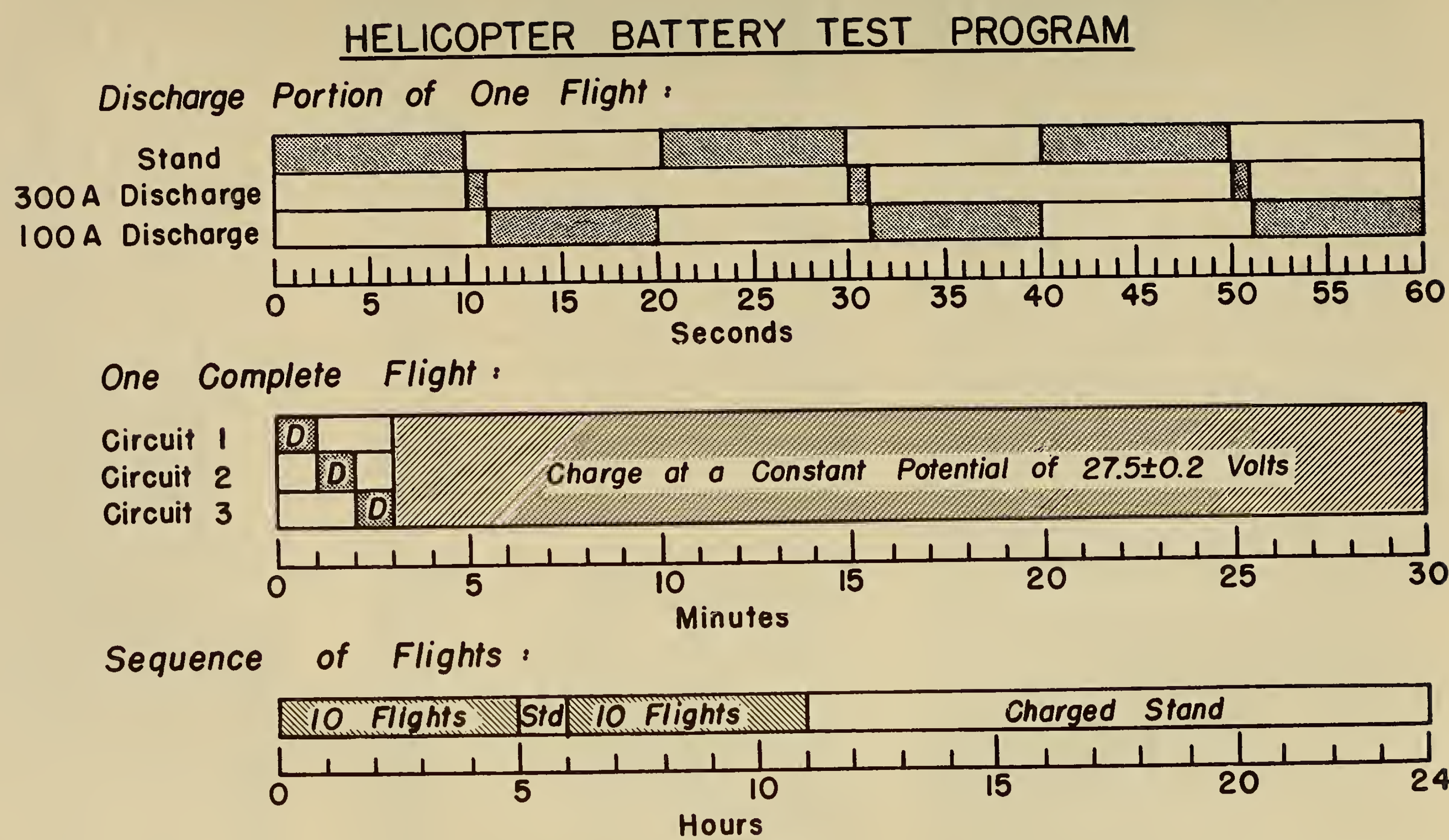


Figure 9 Sequence diagram for the complete simulator test program.

The three charging circuits were identical and were of the modified constant-potential type, i.e., a resistor of low value was placed in the circuit between the battery and the constant-potential bus. In this case the resistor was nominally 0.1 ohm and was adjusted so that the total resistance between battery terminals and the bus bars was 0.1Ω ± 1%. The charging current was furnished by a 28-volt, 150-ampere motor generator whose output was regulated by an aircraft-type carbon-pile regulator. The potential-sensing coil of the regulator was placed across the bus bars so that the potential of the latter remained constant and unaffected by the voltage drop between the generator (G)* terminals and the busses. The regulator was modified so that the rheostat for adjusting the potential would be on the control panel of the simulator. The bus voltage was monitored by a voltmeter and each charging circuit was provided with an ampere-hour meter and a 50-ampere shunt.

The discharge circuits were provided with only OFF or automatic positions because of the shortness of the discharges. The control circuits and some of the instrumentation is also shown in figure 8. The contactors used to placed the batteries on low-rate discharge are controlled by RC1-1, RC1-2, and RC1-3. The high-rate contactor is controlled by the electronic timer. The charging contactors are controlled by RC1-4. Two other control-circuits RC1-5 and RC1-6 are required for the generator and some of the instrumentation. The circuitry is straight forward and requires no further discussion except to note that provisions have been provided to manually operate all control function except the discharge by means of 3 position toggle switches. These switches have an automatic and a manual position. Because of the length of the discharge, only an automatic or OFF position were provided for that function. All power for all of the contactors was obtained from the generator instead of the simulator power and supply. Pilot lights were provided to indicate when (1) each battery is in the discharge portion of the cycle, (2) the low-rate contactor is operating and (3) the charging contactor is operating.

4.2. Instrumentation

The instrumentation of the simulator is manual and automatic. In testing helicopter batteries the following data were desired or needed for control; in each case the letter in brackets indicates whether the method of recording was manual [M] or automatic [A].

1. Start No. [M]
2. Discharge current [M]
3. Discharge Voltage [A] [M]
    a. High-rate
    b. Low-rate
4. Charging Bus voltage [M]
5. Charging current [A] [M]
6. Ampere-hour input [M]
7. Battery temperature [A]

Each of these are discussed below.

4.21. Start Counter

Each discharge circuit is provided with a resettable counter which is connected across the coil of the low-rate contactor (It is designated as CNT in fig. 8).

4.22. Discharge Current

The discharge current is monitored manually by a 0-400 amp 2% ammeter (AMM) and is located in the discharge circuit as shown in figure 8.

4.23. Discharge Voltage

The discharge voltage can be measured manually or automatically using an oscillograph. Manual readings are made by connecting an appropriate voltmeter to the terminal provided on the front panel. To eliminate an IR drop from the battery to the simulator separate voltage leads are provided. The automatic recording is done by a Model BL202 Brush two-channel oscillograph driven by a Model BL928 dual-channel amplifier. Since the total chart width of this type of instrument is only 4-cm. per channel it was necessary to devise a method for expanding the scale to provide adequate resolution. To achieve such resolution it was necessary to have two circuits, one for the high-rate and one for the

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*The details of the generator and regulator are not shown since it would depend on the actual machine used.

low-rate discharge, in which most of the voltage to be measured was bucked out by a known voltage. The complete measuring circuit used to do this is shown in figure 10. Zener diodes were selected as the reference voltage source; two diodes were used, one eleven-volt diode for the high-rate and one eighteen-volt diode for the low-rate discharge. The oscillograph was so programmed that the amplifier was turned on one hour before the first discharge and remained on throughout the flight day. Since the instrument requires fairly frequent calibration, auxiliary programs were arranged so that the instrument would have a calibration recorded at the beginning of each flight, immediately preceding the first start. The operation of the overall circuit is as follows:

The details of the circuit used to record the discharge voltage is shown in figure 10. The points at which the circuit is connected to the balance of the simulator circuit are indicated on both figures 8 and 10. As noted above the amplifier for the oscillograph is kept under power throughout the flight day, being turned off immediately following the last flight of the day. Likewise the zener diode reference voltage sources are kept under power at all times that the generator is operating to insure stable operating temperature. The balance of the circuit is only operative during the one-minute intervals that either RC1-1, RC1-2, or RC1-3 are operated (the control relays for discharging the individual batteries). When one of these relays is operated, power is applied to the circuit at x (see figs. 8 and 10). This causes relays D and E to operate but not A. The latter is not operated because RD is operated thus opening the circuit to A (Note that RD is also responsible for the operation of the RC1-relays hence the contacts on RD shown in figure 10 will open <u>before</u> the power is applied to x). Relay D controls the chart drive motors in the oscillograph. Relay E transfers power for the zener diode from the negative bus to the negative terminal of the battery being discharged via the voltage lead to the battery. Since the total current drain for the two zeners is less than 30 ma and since the voltage lead is about 10 ft. of No. 14 wire the resultant voltage drop is very small and can be ignored.

Cams 2 and 3 are used for instrumentation. Referring back to the sequence diagram (fig. 7), it can be seen that these contacts close at the same time. The contacts of cam 2 operate RD upon closure. As long as RD remains operated relay A will remain unoperated so that the test battery will not be connected to the input of the amplifier. During the interval that the contacts on cams 2 and 3 are closed, relay B will be operated (see in figs. 8 and 10). This period is of approximately 3 seconds duration (see fig. 7) and during the interval a calibration signal of 1.5 v.d.c. is applied to both inputs of the amplifier. When the contacts on cam 3 open, the calibration signal is removed, and no signal is applied to the input of the amplifier thereby recording the zero of the instrument. When the contacts of cam 3 open, RD is released thus closing the contacts that operate A (see fig. 10). The operation of A connects the difference between the zener reference voltages and the test battery to the input of the oscillograph (amplifier). Since the voltage per unit deflection can be calculated from the calibration traces and since the zero trace corresponds to the zener reference voltage, the battery voltage during discharge can be calculated from the traces. Provisions were made for measuring the zener voltages by means of a voltmeter to check the stability. Good agreement was found between the automatic method and the manual method.

4.24. Charging Bus Voltage

The charging bus voltage was monitored by a special suppressed zero voltmeter [3] having a range of 27.0 to 28.0 volts. This instrument was designed at the National Bureau of Standards, and has an accuracy of 0.1 percent, and the smallest scale division is 0.02 volt. Since the voltage range to be monitored on the simulation was 0.2 volt, it was easily readable from a distance. To facilitate adjustment of the bus voltage the control rhesostat for the voltage regulator was mounted directly under the voltmeter.

4.25. Charging Current

The charging current may be monitored manually from the front panel of the simulator or recorded automatically on a 6-point strip chart recorder. One channel is used for each battery. The signal to operate the recorder is derived from the same 50-ampere 50-millivolt shunts as those used for manual monitoring. An appropriate resistance network was used to match the output of the shunt to the input of the recorder so that the full scale of the recorder was 10 amperes.

4.26. Ampere-hour Input

The input on charge was measured by conventional 10-ampere ampere-hour meters (A.H.M.). Their location in the circuit is shown in figure 8. The meters were calibrated over the range of currents that were normally encountered. Although they were adjusted to indicate correctly at currents in the range of 10 amperes upward, they were found to require large corrections at the low currents. Since the current, on charge, varied more or less exponentially and the final current was often very low the meters could not be relied on to more than 10%, while at constant current they could be relied on to about 1-2 percent. If a more precise determination of charging 1% the current was required, the time-current curve had to be integrated.

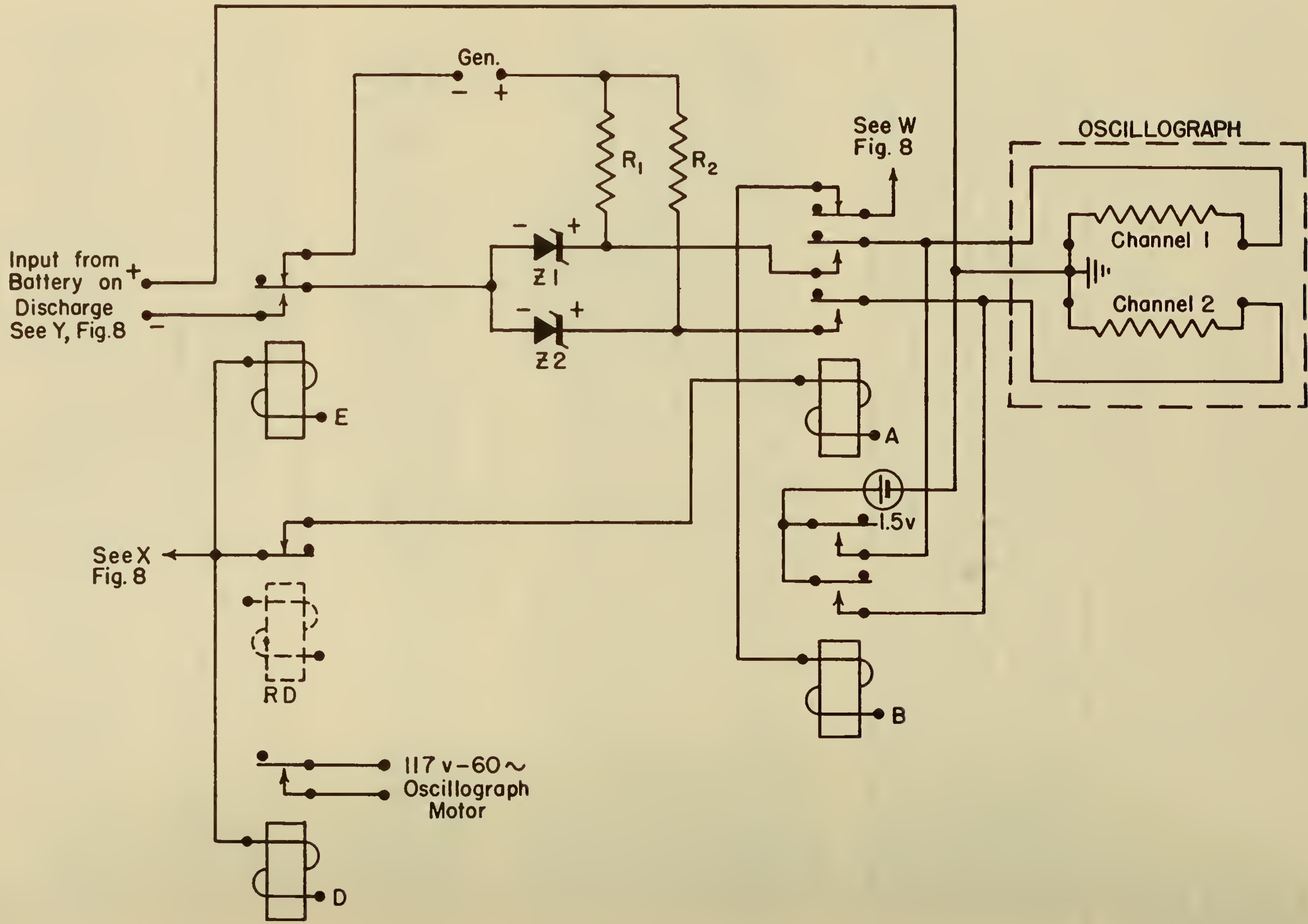

Figure 10 Circuit for recording battery discharge voltage.

5. Discussion

The foregoing section describes the design and operation of a helicopter battery service simulator. This unit has been in operation at the National Bureau of Standards since March 1959 and has performed very well over a period of nearly three years. Furthermore as a result of the operating experience gained in the past years it is possible to suggest the following changes in the present design to improve the overall performance of the simulator:

1. It would be desirable to incorporate control switches in the program circuits so that the program-control relay RC1 can be operated manually or turned off without disturbing the programmed circuit. Such switches should be located in the lower portion of the relay rack to avoid accidental operation.

2. Interlocks and check circuits should be installed between the various programs if full unattended automatic operation is to be desired. These are not absolutely necessary as the overall circuit design is extremely reliable; however, they would afford additional protection against operator error or the failure of one or more components. Such circuits should be the "fail-safe" type, i.e., the failure of any component would shut the whole operation down.

3. The regulation of the constant-potential source should be improved. The present source consists of a motor-generator set with the output of the generator being regulated by an aircraft-type carbon-pile voltage regulator. Although the arrangement probably duplicates the actual condition encountered in service, it was found that it was necessary to adjust the charging voltage manually several times daily in order to keep within the specified limits. A servo or equivalent type of voltage regulator should be devised to keep the bus voltage to within ±0.05 volt or better of the specified value.

4. The method of automatically integrating the current input (presently using ampere-hour meters) should be changed so that a wide range of currents can be accurately integrated. Such an integrator should be capable of accurately integrating a current that changes exponentially with time.

5. The last and probably the most important change is in the manner in which the data is obtained. Because of the large number of charges and discharges the amount of data recorded on the oscillograph and the strip chart recorder is extremely large, and presents a rather serious problem in data reduction. The simplest solution to the problem would be to replace both recorders with equipment that would record the data in a form so that it could be fed directly into a computer for processing. In fact if such instrumentation were provided the ampere-hours meters could be dropped since the current time data could be integrated directly in the computer.

These changes although not absolutely necessary would increase reliability of the simulator and at the same time reduce the labor required to obtain usuable data. Furthermore, it would be a step toward the development of a fully automatic battery tester.

6. References

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[3] W. G. Eicke, Jr. Technical Note, in preparation.

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